Fermi/GBM view of Magnetar Bursts: Bursts, Burst Active Episodes & Burst Induced Changes

Ersin Göğüş
Sabancı University, Istanbul

in collaboration with the Fermi/GBM team
General Properties of Magnetars

- Slowly rotating systems ($P_{\text{spin}} \sim 2 - 12$ s)
- Rapidly spinning down ($dP/dt \sim 10^{-13} - 10^{-11}$ s/s)
- Bright X-ray sources ($L \sim 10^{34} - 10^{35}$ erg/s)
- Transient magnetars ($L \sim 10^{32}$ erg/s in quiescence)
- Young systems as deduces from their galactic locations
- Unique X-ray spectral properties
- Characterized by bright hard X-ray / soft gamma ray bursts
Typical Magnetar Bursts

- Brief (~0.1–few s)
- Irregular times between bursts (seconds - years)
- Diverse time profiles
- Intense ($\sim 10^{36} - 10^{41}$ erg/s)
- Distinct from giant flares in duration, luminosity and energy spectrum
Intermediate Events

Woods & Thompson 2006
More Intermediate Events

SGR 1550–5418

Mereghetti et al. 2010

SGR 1806–20

Gözüsz et al. 2010
Giant Flares

**SGR 0526–66**

Mazets et al. 1979

**SGR 1900+14**

Hurley et al. 1999

**SGR 1806–20**

Hurley et al. 2005
The Gamma-ray Burst Monitor

- 4 x 3 NaI Detectors with different orientations.
- 2 x 1 BGO Detector either side of spacecraft.
- View entire sky while maximizing sensitivity to events seen in common with the LAT

The Large Area Telescope (LAT)

GBM BGO detector
- 200 keV – 40 MeV
- 126 cm², 12.7 cm
- Triggering, Spectroscopy
- Bridges gap between NaI and LAT.

GBM NaI detector
- 8 keV – 1000 keV
- 126 cm², 1.27 cm
- Triggering, Localization, Spectroscopy.
1. GBM magnetar burst catalog

2. Activity based classification of magnetars

3. Burst induced effects in:
   - Persistent soft & hard X-ray emission
   - Pulse profile
   - Source environment
<table>
<thead>
<tr>
<th>Magnetar</th>
<th>Active Period</th>
<th>Triggers</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>SGR J0501+4516</td>
<td>Aug/Sep 2008</td>
<td>26</td>
<td>New source at Perseus arm</td>
</tr>
<tr>
<td>SGR J1550-5418</td>
<td>Oct 2008</td>
<td>7</td>
<td>Known source - first burst active episodes</td>
</tr>
<tr>
<td></td>
<td>Jan/Feb 2009</td>
<td>117/331+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mar/Apr 2009</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>June 2013</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SGR J0418+5729</td>
<td>June 2009</td>
<td>2</td>
<td>New source at Perseus arm</td>
</tr>
<tr>
<td>SGR 1806-20</td>
<td>Mar 2010</td>
<td>1</td>
<td>Old source - reactivation</td>
</tr>
<tr>
<td>1E 1841-045</td>
<td>Feb 2011</td>
<td>3</td>
<td>Known source - first burst active episodes</td>
</tr>
<tr>
<td></td>
<td>June/July 2011</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>SGR 1822-1606 Swift 1834-0846</td>
<td>July 2011</td>
<td>1</td>
<td>New sources in galactic center region</td>
</tr>
<tr>
<td></td>
<td>Aug 2011</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>4U 0142+61</td>
<td>July 2011</td>
<td>1</td>
<td>Old source - reactivation</td>
</tr>
<tr>
<td>1E 2259+586</td>
<td>April 2012</td>
<td>1</td>
<td>Old source - reactivation</td>
</tr>
<tr>
<td>Unconfirmed Origin</td>
<td>2008-2013</td>
<td>21</td>
<td>Multiple error boxes include new source 3XMM J185246.6+003317</td>
</tr>
</tbody>
</table>
All triggers: temporal properties

Unknown event avg $T_{90} = 61$ ms (known sources avg $\sim 100$ ms)
All triggers: spectral properties
Burst Energetics

**SGR 1550-5418**
Fluence: $7 \times 10^{-9} - 1 \times 10^{-5} \text{ erg/cm}^2$
$E = (2 \times 10^{37} - 3 \times 10^{40}) \text{ d}_5 \text{ erg}$
Flux: $8 \times 10^{-7} - 2 \times 10^{-4} \text{ erg/cm}^2\text{s}$
$L: 5 \times 10^{38} - 1 \times 10^{41} \text{ erg/s}$
*Total Energy Release: $6.6 \times 10^{41} \text{ d}_5 \text{ erg (8-200 keV)}$*

**SGR 1806-20**: $3.0 \times 10^{36} - 4.9 \times 10^{39} \text{ erg}$
**SGR 1900+14**: $7 \times 10^{35} - 2 \times 10^{39} \text{ erg}$
**SGR 1627-41**: $10^{38} - 10^{41} \text{ erg}$

**SGR 0501+4516**: $2 \times 10^{37} - 1 \times 10^{40} \text{ erg}$
**1E 2259+586**: $5 \times 10^{34} - 7 \times 10^{36} \text{ erg}$
NEW: GBM Bursts detected since Fermi launch
SYNERGY: Swift-Fermi-RXTE-IPN

Old source reactivation

- SGRs
- AXPs

Kouveliotou et al. 2014
Magnetars with Low Burst Rates

SGR 0418+5729
van der Horst et al. 2010

$B_d = 6 \times 10^{12} \, \text{G}$
Rea et al. 2010; 2013

SGR 1833 – 0832
Göğüş et al. 2010
Magnetars with Low Burst Rates

SGR 1822.3–1606 $\Rightarrow$
$B_d = 2.7 \times 10^{13} \, \text{G}$
Rea et al. 2012

SGR 1834.9–0846
Esposito et al. 2012

SGR 1745–29 $\Rightarrow$
Kannea et al. 2013
Magnetars with Low Burst Rates

How can sources with low dipole magnetic fields (e.g., SGR 0418+5729 or SGR 1822.3–1606) generate bursts?

XMM – Newton observations of SGR 0418+5729 on 2009 August 12 for 65 (36) ks gave the answer: Güver, Göğüş, Özel (2011), Tiengo et al. (2013)
$T_{90}$ Duration of Burst Active Episode

$T_{90}$: Time since the onset of an outburst during which 90% of all observed bursts are recorded.

Onset of a burst active episode: If at least 5 bursts were observed from the same magnetar in 24 hours.

<table>
<thead>
<tr>
<th>Source</th>
<th>Outburst</th>
</tr>
</thead>
<tbody>
<tr>
<td>SGR 1550–5418</td>
<td>2009</td>
</tr>
<tr>
<td>SGR 1627–41</td>
<td>1998</td>
</tr>
<tr>
<td>SGR 0501+4516</td>
<td>2008</td>
</tr>
<tr>
<td>SGR 1900+14</td>
<td>1998, 2002</td>
</tr>
</tbody>
</table>

Göğüş 2014

Göğüş 2014
SGR 1900+14: 1998, 2002

SGR 0501+4516 (2008)
SGR 1550+5418 (2009)
## $T_{90}$ of Burst Active Episode

<table>
<thead>
<tr>
<th>Source</th>
<th>$T_{90}$–BurstActivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>SGR 1550–5418 (2009)</td>
<td>5.6 days</td>
</tr>
<tr>
<td>SGR 1627–41 (1998)</td>
<td>9.1 days</td>
</tr>
<tr>
<td>SGR 0501+4516 (2008)</td>
<td>6.3 days</td>
</tr>
<tr>
<td>SGR 1900+14 (1998)</td>
<td>183 days</td>
</tr>
<tr>
<td>SGR 1806–20</td>
<td>112 – 311 days</td>
</tr>
</tbody>
</table>

Burst active episode of a prolific transient lasts less than 10 days.
# Classification of Magnetars Based on Their Bursting Behavior

<table>
<thead>
<tr>
<th>Prolific Bursters</th>
<th>Prolific Transients</th>
<th>AXPs with SGR-like Bursts</th>
<th>Transients with Low Burst Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>SGR 1900 + 14</td>
<td>SGR 1627 - 41</td>
<td>1E 1048-5937, 1E 2259+586</td>
<td>SGR 0418 + 5729</td>
</tr>
<tr>
<td>SGR 1806 – 20</td>
<td>SGR 1550 - 5418</td>
<td>4U 0142+61, 1E 1841-045</td>
<td>SGR 1833 - 0832</td>
</tr>
<tr>
<td>SGR 0526 – 66</td>
<td>SGR 0501 + 4516</td>
<td>CXO J164710.2-455216</td>
<td>Swift 1822.3 – 1606</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>XTE J1810-197</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Swift 1834.9– 0846</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AX J1818.8 - 1559?</td>
<td>SGR 1745 – 29, SGR 1935+2154?</td>
</tr>
</tbody>
</table>
SGR 1745–29 & SGR 1833–0832

Flux Decay

X-ray flux of SGR 1745–29 is constant for ~10 days following the onset

Similar flux trend was seen in SGR 1833 – 0832

Continuous heating of the crust by trapped fireball?

Kannea et al. 2013
SGR 1550-5418 = 1E 1547.0-5408

ASCA, XMM: “Magnetar Candidate” Gelfand & Gaensler 2007
Radio observation: \( P = 2.0698 \text{ s}, \ \dot{P} = 2.3 \times 10^{-11} \text{ s / s} \)
\( B = 2.2 \times 10^{14} \text{ G} \rightarrow \text{Magnetar} \) Camilo et al. 2008

SGR-like bursts:
- Oct 2008 (~1 week)
- Jan-Feb 2009 (~1 month)
- Mar-Apr 2009 (~1 month)

Most intense bursting on January 22, 2009
~450 bursts
GBM Trigger 090122037

- Trigger at 00:53:52 UT on January 22, 2009
- 1st of 41 GBM Triggers
- Trigger data for 600 s
- 58 untriggered bursts identified within 600 s

Enhanced Persistent Emission

Kaneko et al. 2010
Pulsation Detection

(a) 12-27 keV
(b) 27-50 keV
(c) 50-102 keV
(d) 102-293 keV
Timing Analysis

Lomb – Scargle test:

P: 0.1 → 10 s in 50 – 100 keV

\[ P = 2.0699 \pm 0.0024 \text{ s} \]

Coherent signal: strongest in \( T_0 + 120 – 210 \text{ s} \)

No other episode of pulsations on this day or the following four days.
Pulse Profiles

- Double peaked at low E
- Single peak at high E
- No pulsation > 110 keV

(a) 10 – 14 keV
(b) 14 – 22 keV
(c) 22 – 33 keV
(d) 33 – 50 keV
(e) 50 – 74 keV
(f) 74 – 110 keV
RMS Pulsed Fraction Spectrum

- Correlates with energy
- Peaks in 50 – 74 keV
- Not significant > 110 keV
- Indication of a “dip”
Spectral Analysis

Time Integrated Spectrum \([T_0 + 72 – 248 \text{ s}]\)

8 – 909 keV Burst Free

Power Law

Total Energy
\[4.3 \times 10^{40} \text{ ergs}\]

Additional Blackbody \((kT = 18 \text{ keV})\):
\[\Delta C_{\text{stat}} = 13.5 \text{ (for 2 DOF)}\]
Time Resolved Spectra ($\nu F_{\nu}$)

$[T_0 + 72 – 117, 122 – 169, 173 – 223 \text{ s}]$

74 – 117 s  Power Law only  (Blackbody is not needed)

122 – 169 s  Power Law

173 – 223 s  Power Law

$F_{BB}/F_{TOTAL} = 26\%$

25\%
# Evidence of the Blackbody Component

## Temporal Properties
- Pulsations most significant in 120 – 210 s
- Pulse fraction peaks in 50 – 74 keV
- Pulsations not seen above 110 keV

## Spectral Properties
- Blackbody required in 122 – 223 s
- Blackbody $kT \sim 17$ keV
- $F_{BB} \rightarrow 25\%$
- $F_{PWRL} \rightarrow 75\%$
Blackbody: Radius of the Emitting Region

Assuming a hot spot of radius $R_{HS}$ on the neutron star surface

For $D = 5$ kpc, $kT = 17$ keV :

$A_{HS} \approx 0.044 \left(\frac{D}{5 \text{ kpc}}\right)^2 \text{ km}^2$

$\rightarrow R_{HS} \approx 120 \text{ m}$

$\rightarrow$ Sign of a trapped fireball

Kaneko et al. 2010
The GBM Magnetar Team

- C. Kouveliotou (NASA/MSFC, USA), G. Younes (USRA, USA), S. Guiriec (UoMD, USA)
- M. Baring (Rice University, USA)
- E. Göğüş, Y. Kaneko, (Sabancı University, Turkey)
- A. Watts, A. van der Horst, D. Huppenkothen, M. van der Klis, R. Wijers, T. van Putten (U. of Amsterdam, The Netherlands)
- O. Kargaltsev (GWU), G. Pavlov (PSU)
- J. Granot (The Open University, Israel)
- J. McEnery, N. Gehrels, A. Harding (NASA/GSFC, USA)
- L. Lin (APC, U of Paris, France)